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Fundamentals of Satellite Remote Sensing

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Satellite Remote Sensing of Air Quality: Data, Tools, and Applications

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Indian Institute of Tropical Meteorology, Pune, India

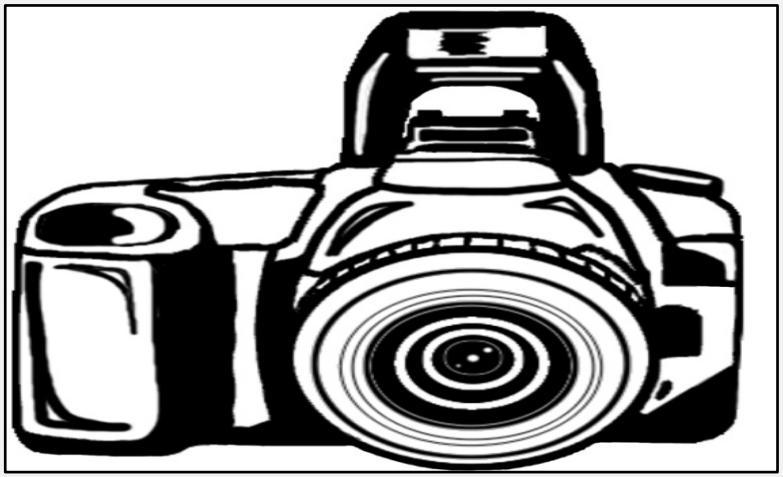
Objectives

By the end of this presentation, you will be able to:

- outline what the electromagnetic spectrum is
- outline how satellites detect radiation
- name the different types of satellite resolutions

What is remote sensing?

Collecting information about an object without being in direct physical contact with it

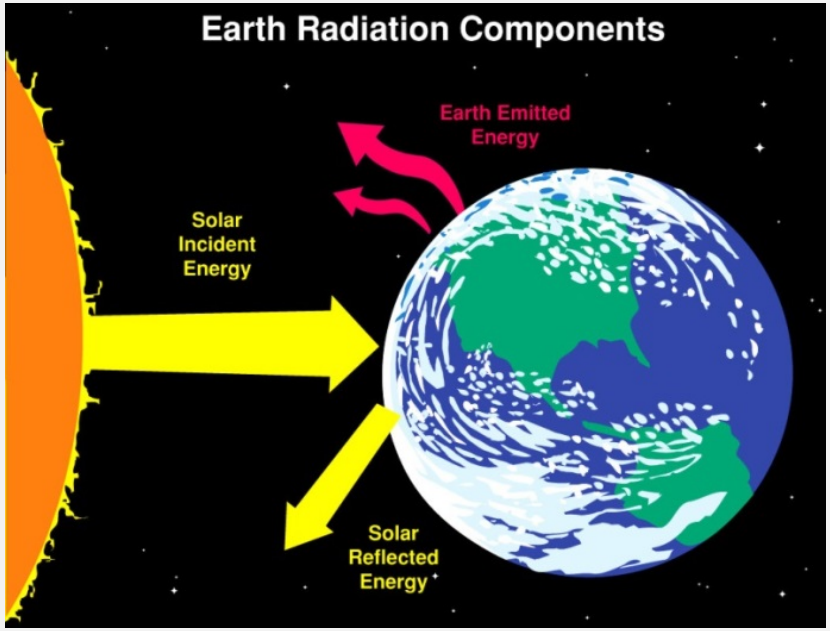


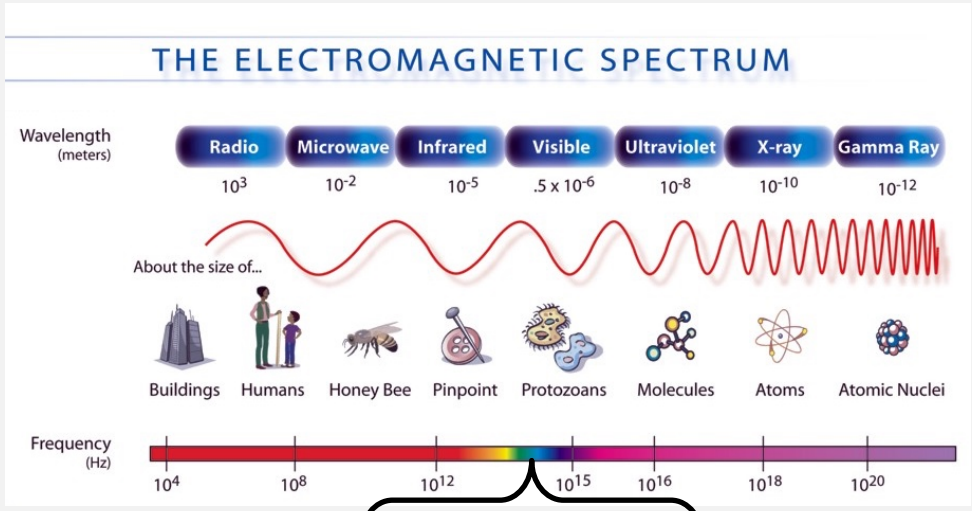
Remote Sensing: Platforms

- The platform depends on the end application
- What information do you want?
- How much detail do you need?
- What type of detail?
- How frequently do you need this data?

Electromagnetic Radiation

- Earth-Ocean-Land-Atmosphere System
  - Reflects solar radiation back into space
  - Emits infrared and microwave radiation into space



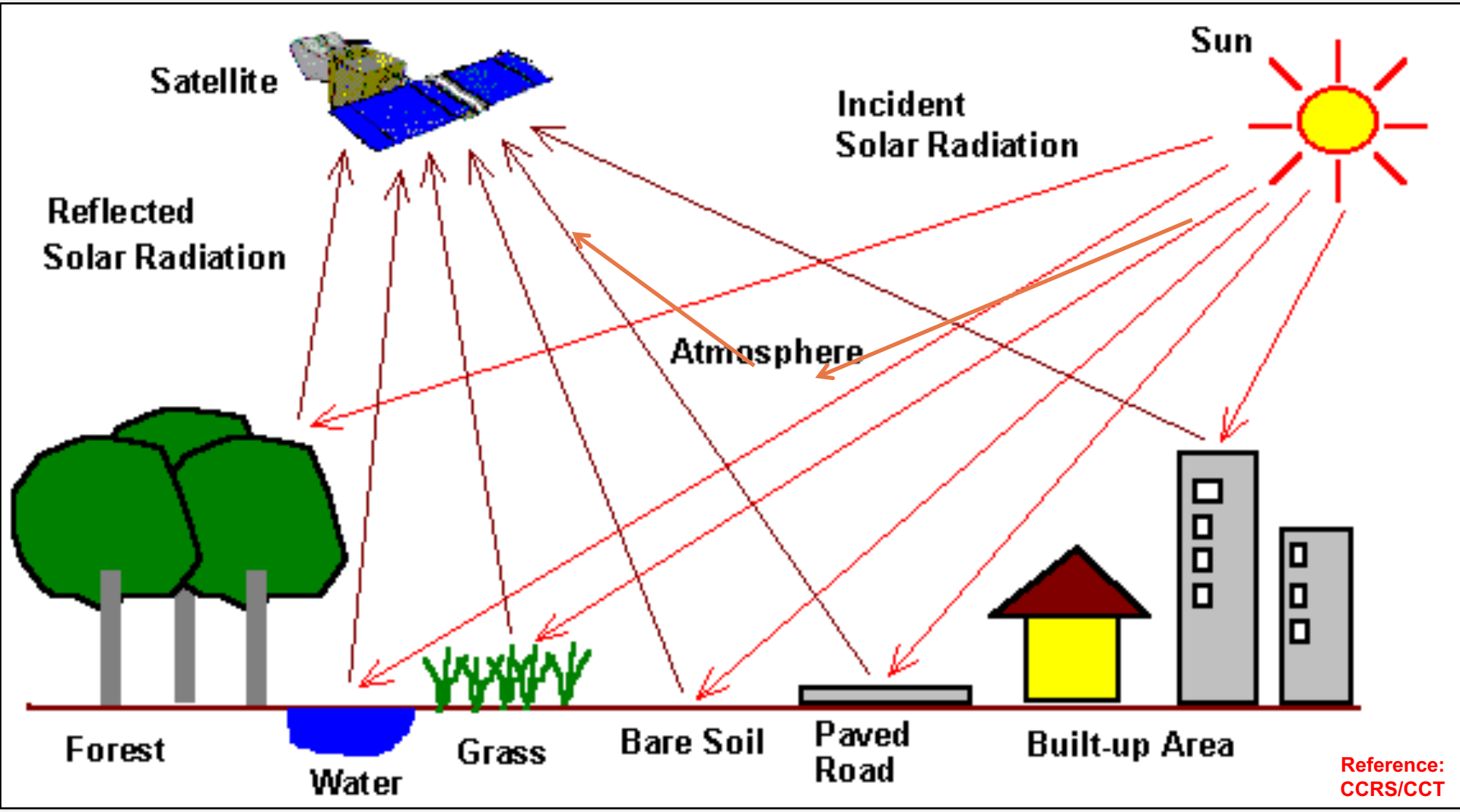


visible

~ 0.7 ~ 0.4

micrometers

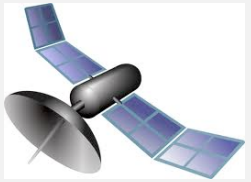
What do satellites measure ?

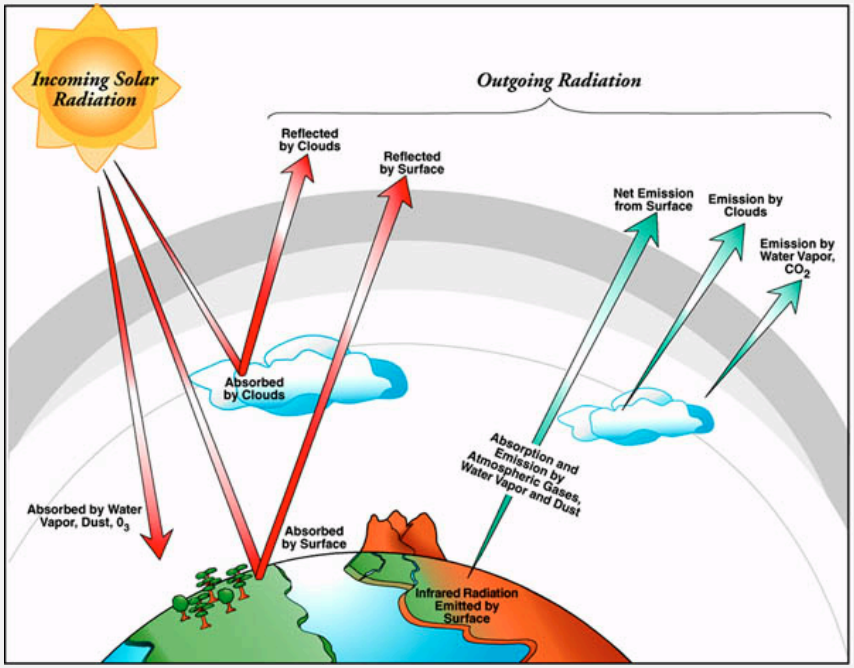


Measuring Properties of the Earth-Atmosphere System from Space

- The intensity of reflected and emitted radiation to space is influenced by the surface and atmospheric conditions

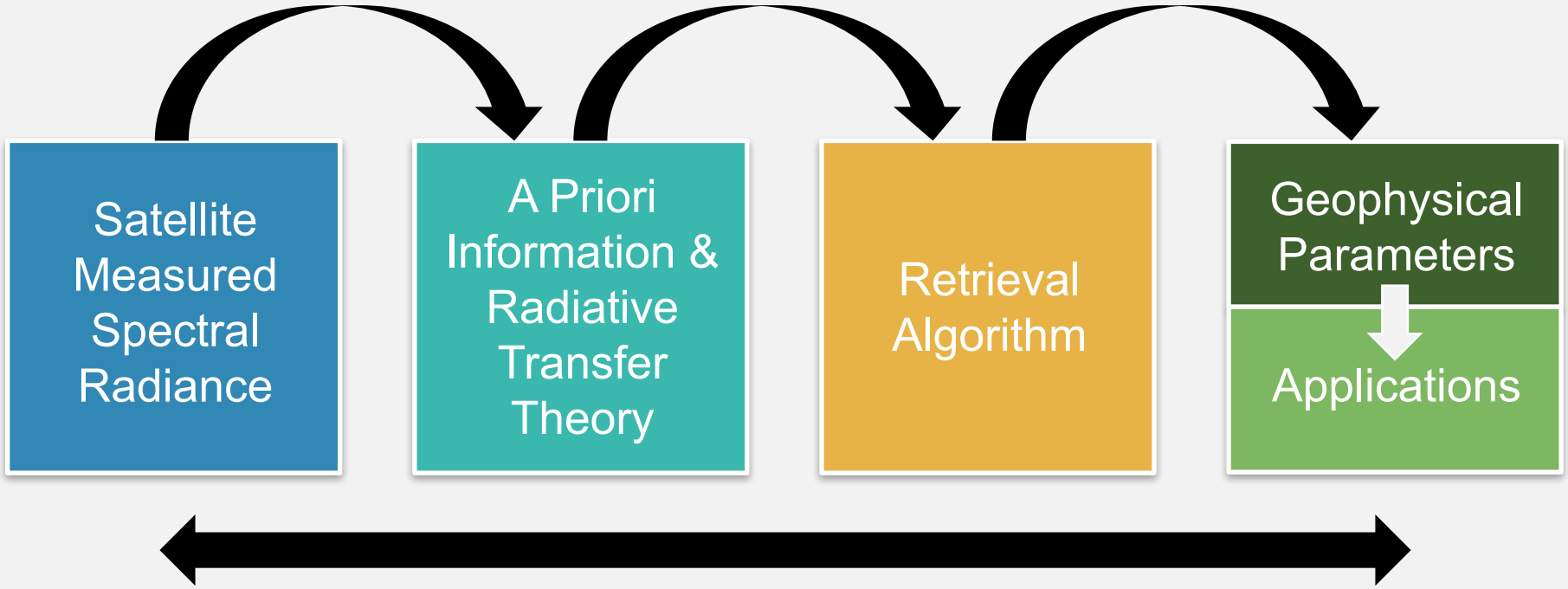
- Thus, satellite measurements contain information about the surface and atmospheric conditions





Credit: University of Maryland

The Remote Sensing Process



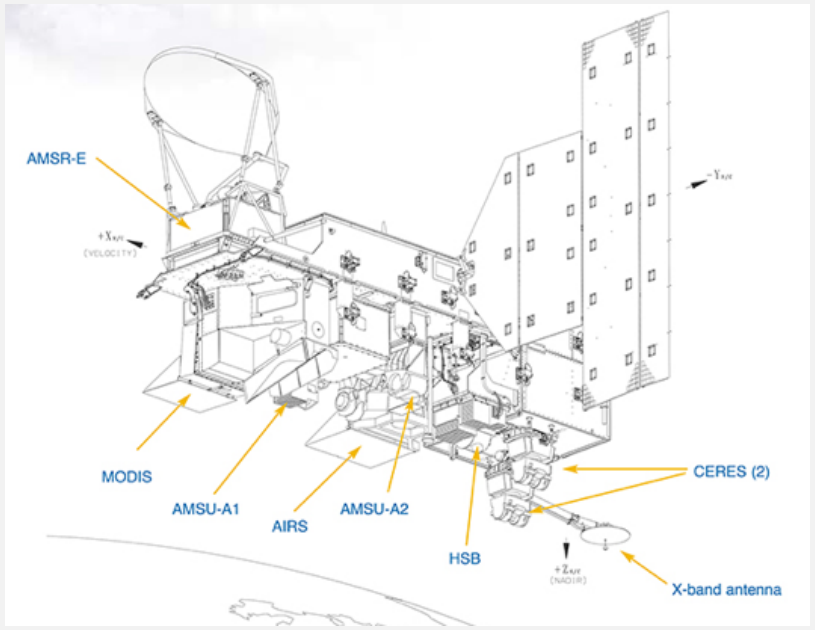
Satellites, Sensors, and Orbits

Satellites vs. Sensors

Earth-observing satellite remote sensing instruments are named according to:

1. the satellite (platform)
2. the instrument (sensor)

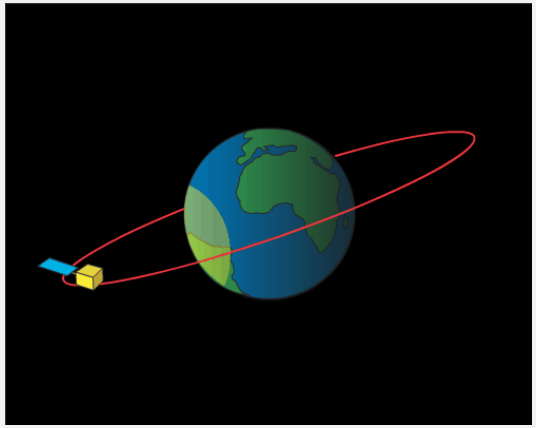
Aqua Satellite

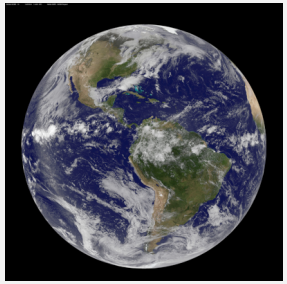


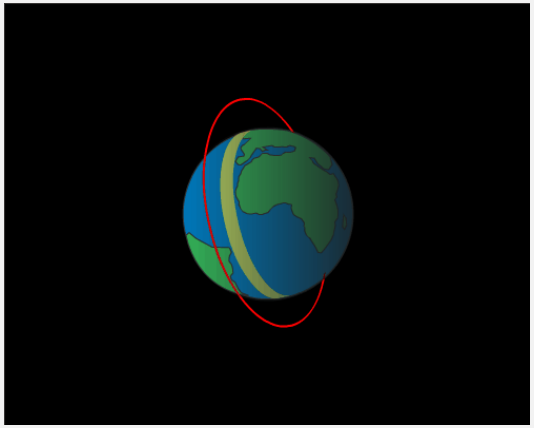
Characterizing Satellites and Sensors

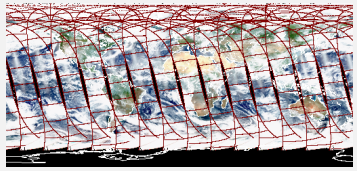
- **Orbits**
  - Polar vs. Geostationary
- **Energy Sources**
  - Passive vs. Active
- **Solar and Terrestrial Spectra**
  - Visible, UV, IR, Microwave…
- **Measurement Techniques**
  - Scanning, Non-Scanning, Imager, Sounders...
- **Resolution (Spatial, Temporal, Spectral, Radiometric)**
  - Low vs. High
- **Applications**
  - Weather, Land Mapping, Atmospheric Physics, Atmospheric Chemistry, Air Quality, Radiation Budget...

Common Orbit Types









Geostationary Orbit

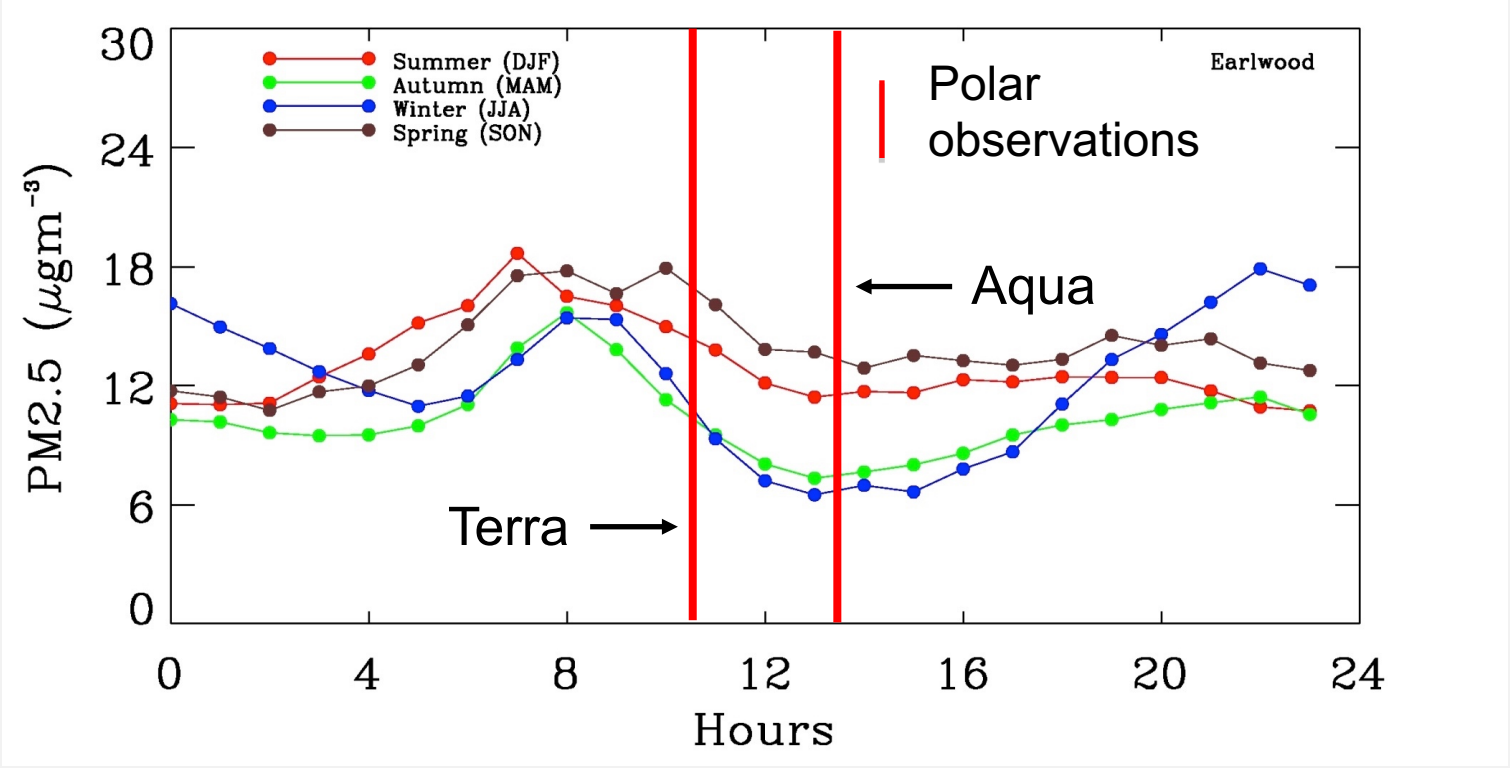
- Has the same rotational period as Earth
- Appears ‘fixed’ above Earth
- Orbits ~36,000 km above the equator

Polar Orbit

- Fixed, circular orbit above Earth
- Sun synchronous orbit ~600-1,000 km above Earth with orbital passes are at about the same **local solar time** each day

Observation Frequency

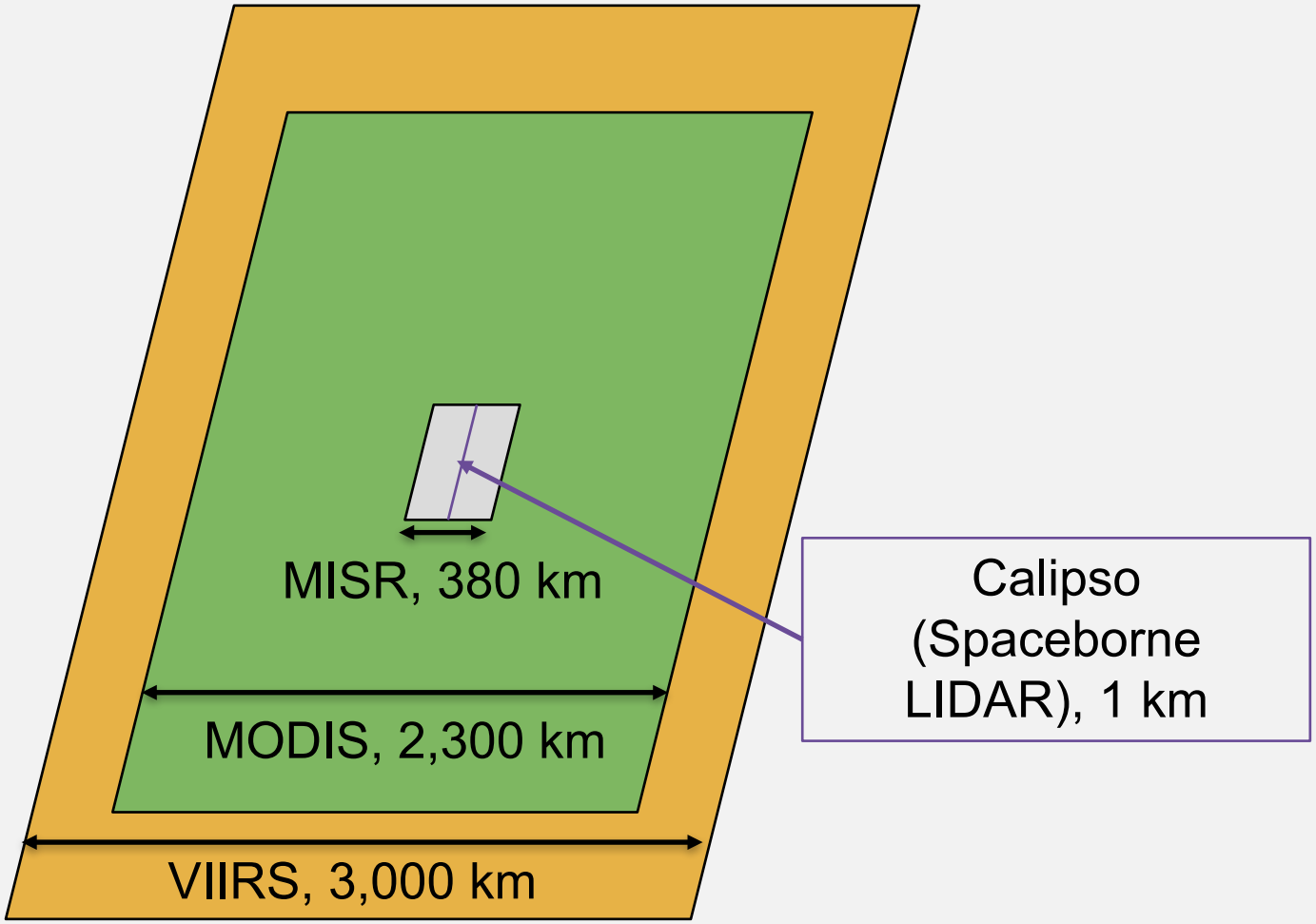
Polar Orbiting Satellites: 1-3 observations per day, per sensor



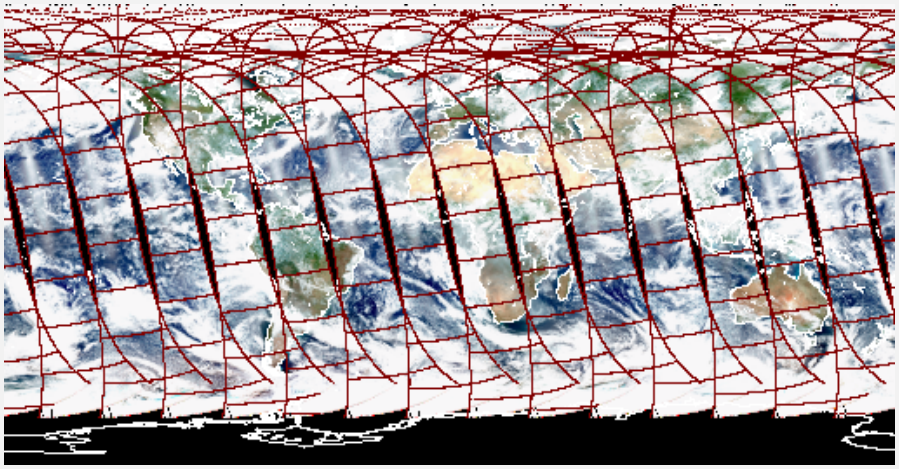
Geostationary Satellites: Every 30 sec. to 15 min.

Future satellites: TEMPO, GEMS, Sentinel-4

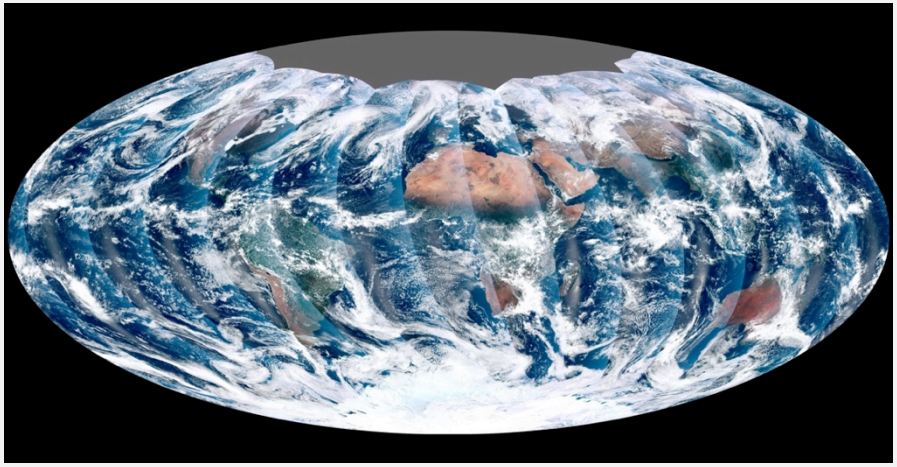
Satellite Coverage



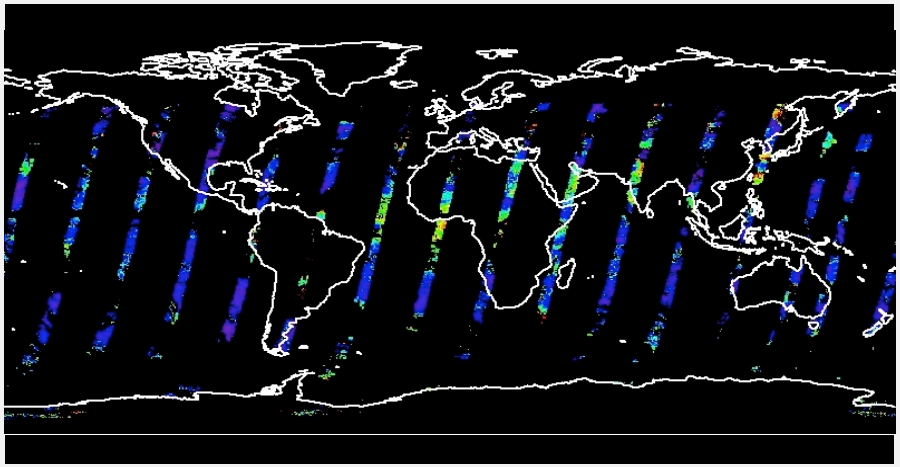
Satellite Coverage



MODIS



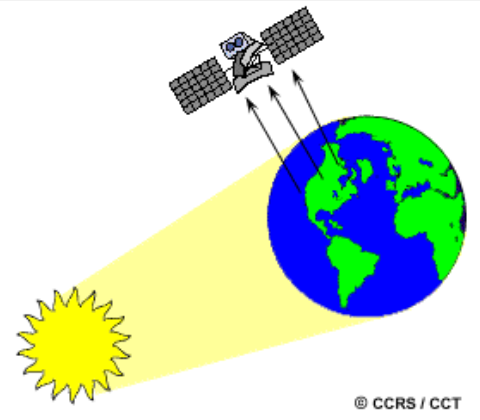
VIIRS



MISR

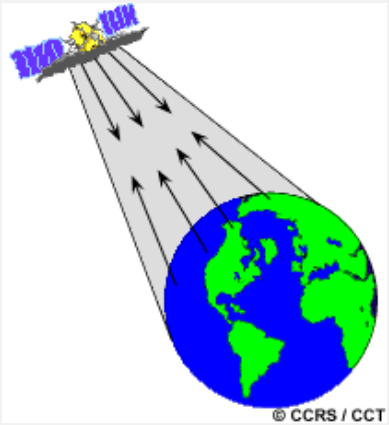
Active & Passive Sensors

Passive Sensors



- Remote sensing systems that measure naturally available energy are called passive sensors
- MODIS, MISR, OMI, VIIRS

Active Sensors



- The sensor emits radiation directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor.*
- CALIPSO

*Text Source: Natural Resources Canada

Active & Passive Sensors

Passive | Sensors detect only what is emitted from the landscape, or reflected from another source (e.g., light reflected from the sun).

Active | Instruments emit their own signal and the sensor measures what is reflected back. Sonar and radar are examples of active sensors.

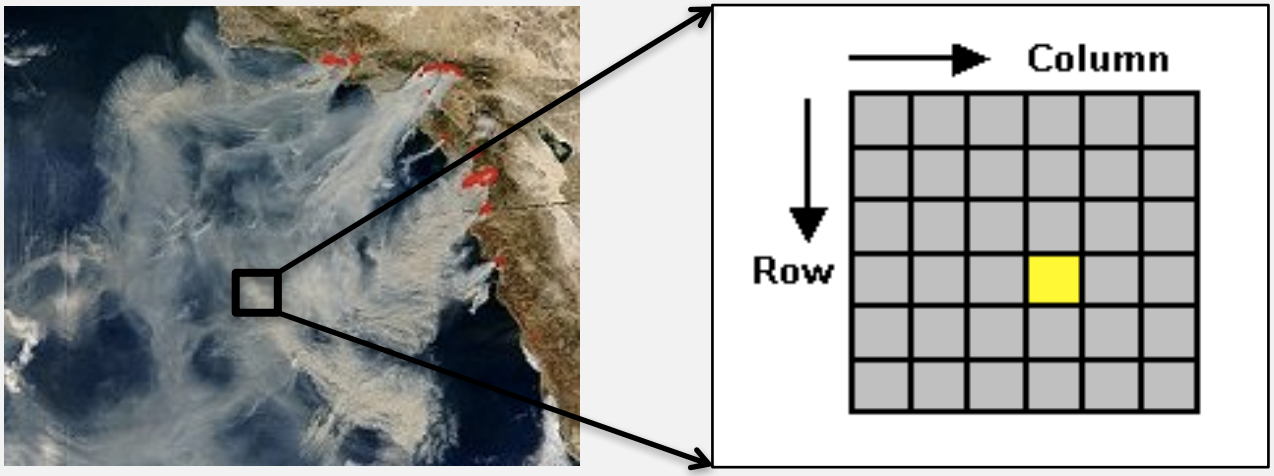

Resolution

Remote Sensing – Types of Resolution

- **Spatial Resolution**
  - Smallest spatial measurement
- **Temporal Resolution**
  - Frequency of measurement
- **Spectral Resolution**
  - Number of independent channels
- **Radiometric Resolution**
  - Sensitivity of the detectors

Depends on the satellite orbit configuration and sensor design. Resolutions are different for different sensors.

Pixel – the Smallest Unit of an Image

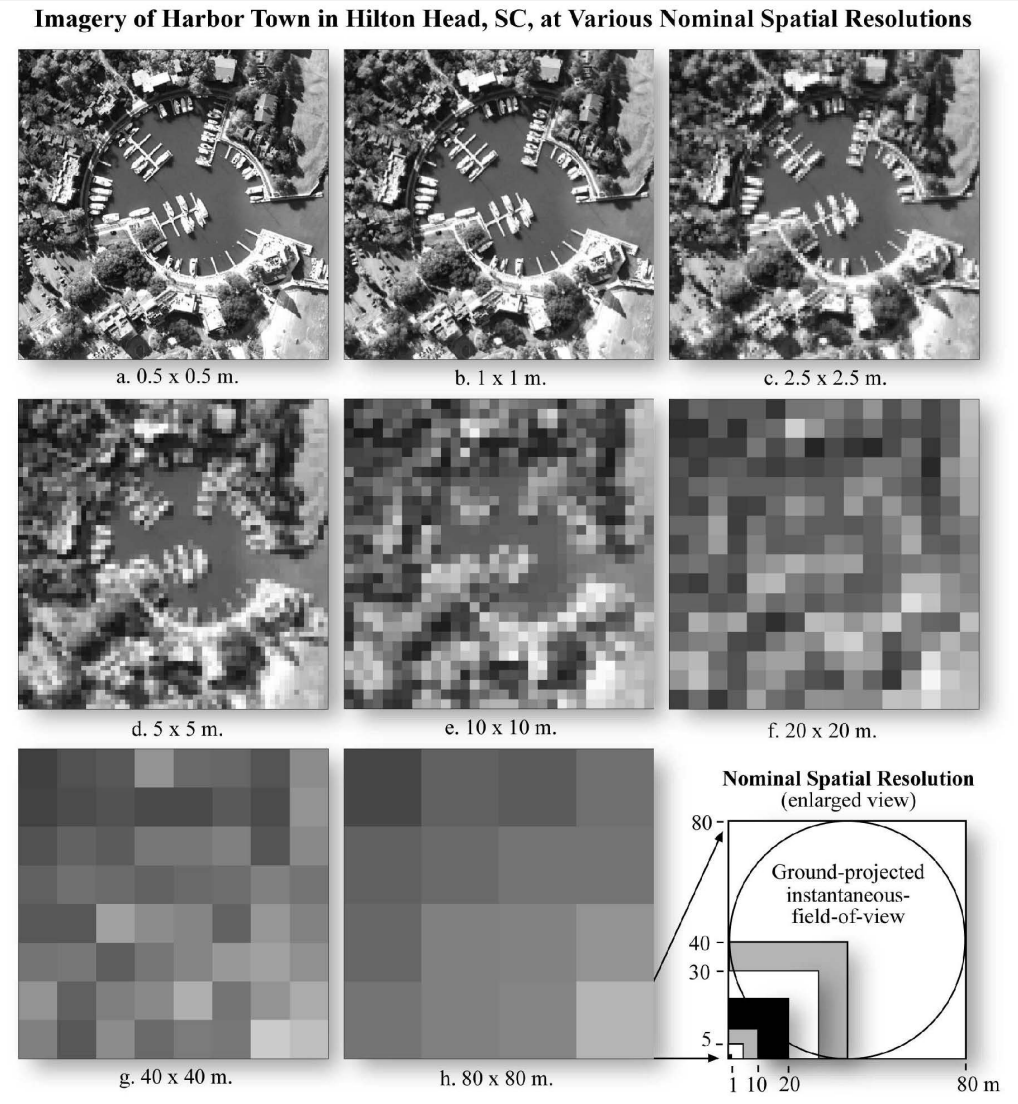


- A digital image is comprised of a two dimensional array of individual picture elements – called pixels – arranged in columns in rows
- Each pixel represents an area on the Earth's surface
- A pixel has an intensity value and a location address in the 2D image
- Spatial resolution is defined by the size of a pixel

*Text Source: Center for Remote Imaging, Sensing & Processing

Why is spatial resolution important?

- MODIS
  - 250 m – 1 km
- MISR
  - 275 m – 1.1 km
- OMI
  - 13x24 km
- VIIRS
  - 375 m

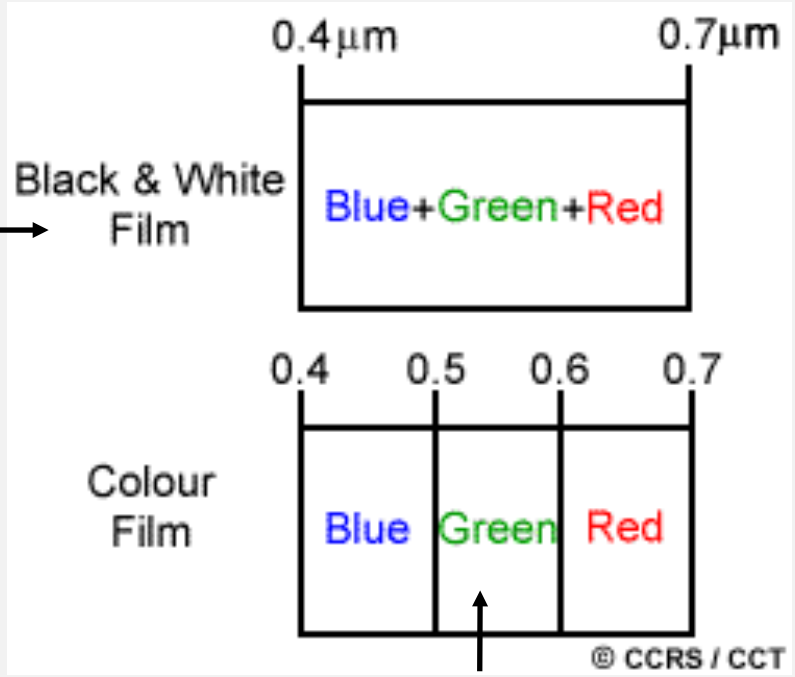


Source: Introductory Digital Image Processing, 3rd edition, Jensen, 2004

Spectral Resolution

- Spectral resolution describes a sensor's ability to define fine wavelength intervals
- The finer the spectral resolution, the narrower the wavelength range for a particular channel or band

- **Multispectral Sensors**
  - MODIS
  - Low spectral resolution
- **Hyperspectral Sensors**
  - OMI, AIRS
  - High spectral resolution



Low Spectral Resolution

High Spectral Resolution

Why is spectral resolution important?

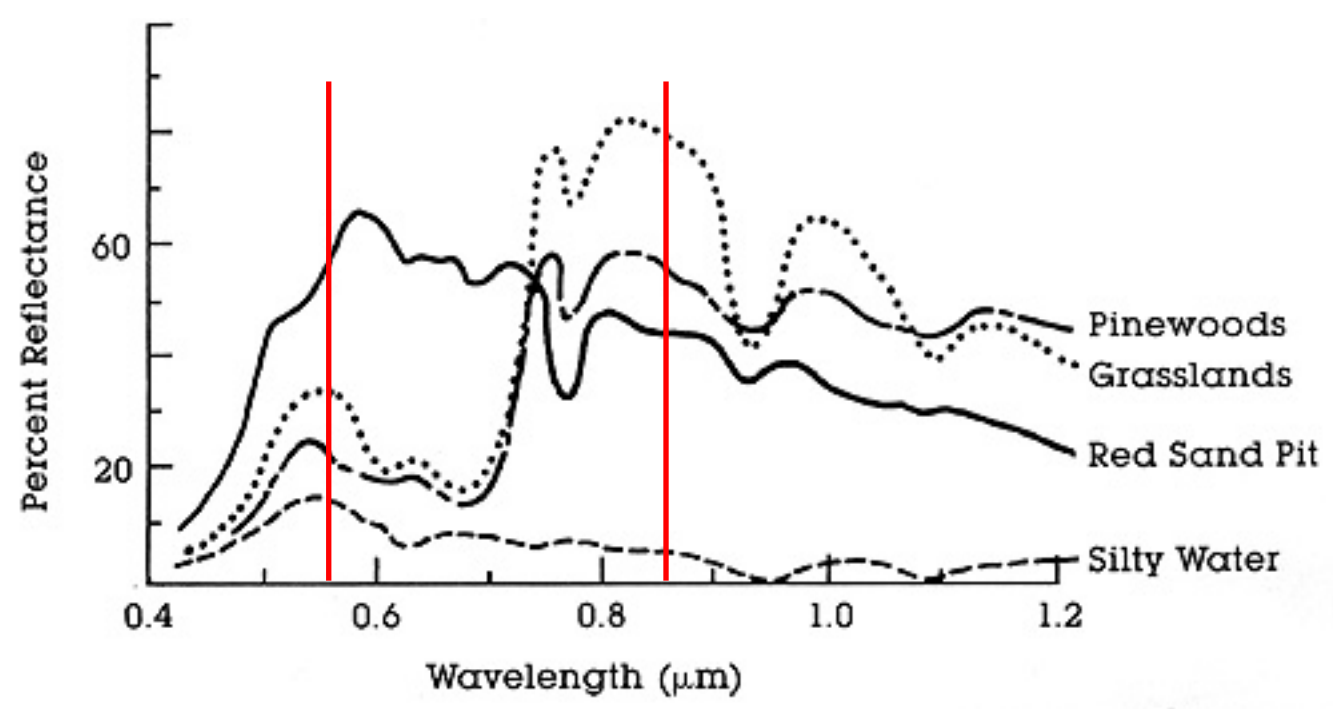


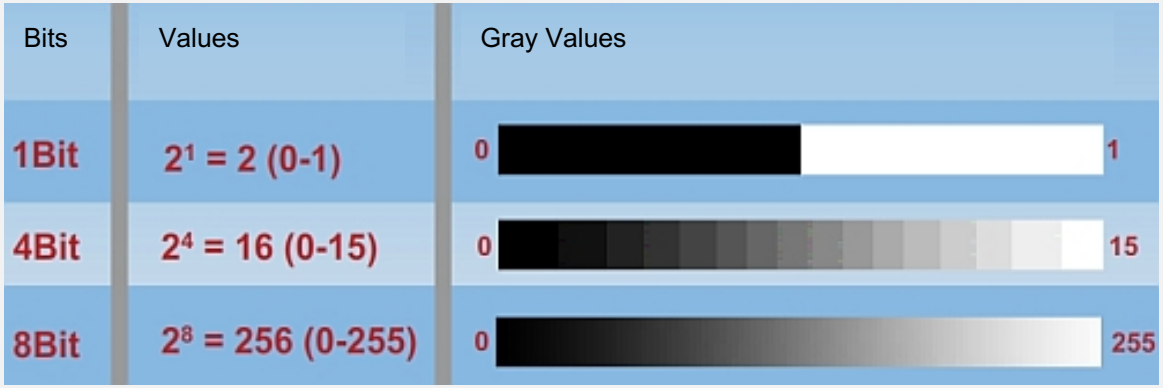
Image Credit: Indian Institute of Science

Radiometric Resolution

- Detects the difference in brightness levels
- The more sensitive the sensor - the higher the radiometric resolution
- If radiometric precision is high, an image will be sharp
- Expressed in bits
- NASA Satellite Sensor Examples:
  - 12 bit sensor (MODIS, MISR): 2^{12} or 4,096 levels
  - 10 bit sensor (AVHRR): 2^{10} or 1,024 levels
  - 8 bit sensor (Landsat TM): 2^{8} or 256 levels (0-255)
  - 6 bit sensor (Landsat MSS): 2^{6} or 64 levels (0-63)

Radiometric Resolution

- Imagery data are represented by positive digital numbers that vary from 0 to (one less than) a selected power of 2
- The maximum number of brightness levels available depends on the number of bits (represents radiometric resolution) used in representing the energy recorded
- The larger this number, the higher the radiometric resolution
- 12 bit sensor (MODIS, MISR)
  - 2^{12} or 4,096 levels
- 10 bit sensor (AVHRR)
  - 2^{10} or 1,024 levels
- 8 bit sensor (Landsat 7 TM)
  - 2^{8} or 256 levels

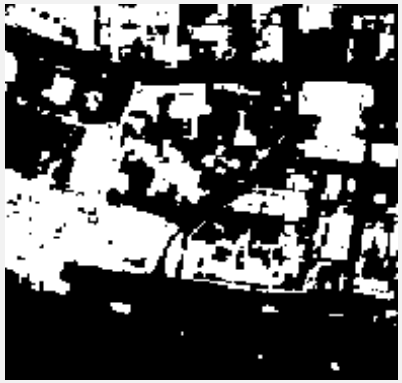


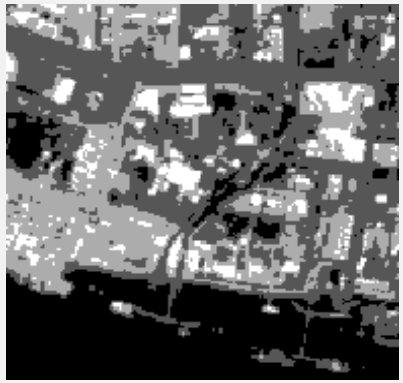
Source: FIS

*Text Source: Natural Resources Canada

Radiometric Resolution

2 - levels





4 - levels

8 - levels

16 - levels

In classifying a scene, different classes are more precisely identified if radiometric resolution is high

MODIS has 4,096 levels

Temporal Resolution

- How frequently a satellite can provide observation of the same area on the earth
- It mostly depends on swath width of the satellite – larger the swath – higher the temporal resolution

- MODIS
  - 1-2 days
- OMI
  - 1-2 days
- MISR
  - 6-8 days
- VIIRS
  - 1 day
- Geostationary
  - 30 sec – 1 hr

Remote Sensing Tradeoff

It is **very difficult** to obtain extremely high spectral, spatial, temporal, **AND** radiometric resolutions, all at the same time

References and Further Reading

- Natural Resources Canada: http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9309
- Center for Remote Imaging, Sensing, and Processing: http://www.crisp.nus.edu.sg/~research/tutorial/image.htm
- NASA Earth Observatory: http://earthobservatory.nasa.gov/Features/RemoteSensing/remote_06.php
- EOS-Goddard: http://fas.org/irp/imint/docs/rst/Front/tofc.html
- Spectral Resolution: http://web.pdx.edu/~jduh/courses/Archive/geog481w07/Students/Cody_SpectralResolution.pdf